Influence of chromaticity correction on beam loss during SIS-100 proton operation

S. Sorge, GSI, Darmstadt, Germany*

In this report, results of multi-particle tracking simulations performed with MAD-X in order to estimate particle loss during SIS-100 proton operation are presented. The proton cycle requires the usage of beam optics which provide $\gamma_{tr} = 45.5$ in order to achieve the extraction energy $E = 29$ GeV without transition crossing. At this stage, a lattice consisting of magnets without errors and a single harmonic rf cavity to simulate synchrotron oscillations was used, where a scenario without acceleration was considered. The working point was $(Q_x, Q_y) = (21.8, 17.7)$ because it fits well in the mesh of resonance lines so that resonance excitation can be minimised.

The large-γ_{tr} lattice causes some difficulties. Besides horizontal beta and dispersion functions with large maxima, one finds the horizontal chromaticity $\xi_x = -2.44$. Assuming the maximum relative momentum deviation $\delta_{max} \equiv \Delta p_{max}/p = \mp 0.0043$ [1], the resulting maximum chromatic tune deviation is

$$\Delta Q_{x,max} = \xi_x Q_x \delta_{max} = \pm 0.23. \quad (1)$$

Hence, the full tune spread is only a little less than 0.5 and, in any case, particles with large momentum deviations will approach an integer or half-integer tune. As a result, beam loss of about 9 % was found in multi-particle tracking simulations, about 1 % is considered as acceptable.

To investigate the generation of particle loss in more detail, single particles were tracked along the closed orbit deviation arising from their momentum deviations δ. In doing so, trajectories in the longitudinal phase space plane were found which are strongly non-symmetric with respect to the sign of δ, see Fig. 1, which is caused by a strong δ dependence of the phase slip factor, $\eta(\delta) = \eta_0 + \eta_1 \delta$. The result is the formation of the fixed point in longitudinal phase space, $(-ct, \delta) = (0, \delta_{FP})$, where $\eta(\delta_{FP}) = 0$, so that particles reach large positive momentum deviations, cross the half-integer resonance at $Q_{x,res} = 21.5$, and become lost. In order to avoid that, the chromaticities were partially corrected using all main sextupoles to reduce the maximum chromatic tune deviations to $\Delta Q_{x,max} = \Delta Q_{y,max} = \pm 0.1$. Correcting two chromaticities, ξ_x, ξ_y with 56 sextupoles allows to apply additional constraints. In order to minimise the non-linear influence of the sextupoles on the beam behaviour, three constraints were applied:

$$\sum_{i=1}^{n_{sext}} (k_2 L)_i^2 \rightarrow \text{min.} \quad (2)$$

$$\sum_{i=1}^{n_{sext}} (k_2 L \beta_x)_i^2 \rightarrow \text{min.} \quad (3)$$

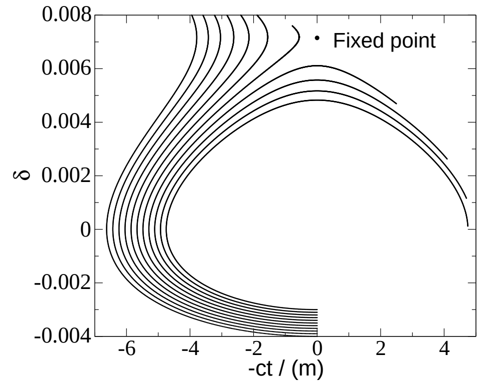

Figure 1: Trajectories in longitudinal phase space of 11 particles started at equidistant δ, $-ct = 0$, and transverse positions of the resulting closed orbit deviation $(x_{co}, x'_{co}) = (D_x, D'_x)\delta$. The chromaticities were not corrected. A fixed point appears at approximately $\delta_{FP} = 0.0071$.

Table 1: δ_{FP} from single-particle simulations, see caption of Fig. 1, and particle loss from multi-particle simulations.

Chromaticity correction	δ_{FP}	P_{loss}
none	0.0071	8.8 %
constraint of Eq. (2)	0.0079	3.4 %
constraint of Eq. (3)	0.0101	0.04 %
constraint of Eq. (4)	0.0101	0.02 %

$$\sum_{i=1}^{n_{sext}} (k_2 L)_i^2 \left(\beta_{x,i}^2 - D_{x,i}^2\right) \rightarrow \text{min.}, \quad (4)$$

where in the 2nd and 3rd constraints the influence of horizontal beta and / or dispersion functions at the locations of the sextupoles were regarded. In doing so, more symmetric longitudinal particle trajectories and larger δ_{FP} could be achieved, see central column of Table 1.

The resulting particle losses, estimated by multi-particle tracking simulations, were found to be strongly reduced due to chromaticity correction, see right column of Table 1. However, the shifts of δ_{FP} obtained with the present settings for the sextupoles were found by chance what is somewhat unsatisfactory. Hence, the study will be continued by searching for a systematic way to set the sextupoles in order to shift δ_{FP} and by the inclusion of systematic and random multipolar errors in dipoles and quadrupoles.

References

[1] O. Chorniy, private communication.

* S.Sorge@gsi.de